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URBAN DRAINAGE AS A FACTOR IN EUTROPHICATION

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by

S. R Weibel

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ABSTRACT

By the year 2000 some 240 million persons, 77 percent of an anticipated 312 million population in the 48 mainland states and the District of Columbia will occupy 22 intensely urbanized areas over the country, on about 11 percent of the area. These are shown on a map. Among them are three large regions identified as the Metropolitan Belt, extending across the northern states from the Atlantic Ocean to the Chicago area, the California Region and the Florida Region. Similarly mapped are the states and their numbers of communities which are wholly or partly served by combined sewer systems. Ninety-eight percent of these also lie in a band across the northern states from coast to coast, and including California. A third factor arises in that all three of the projected large urbanized regions abovementioned have tremendous potentialities for water recreation. The demand for this, and for the necessary water quality will be a sizeable challenge.

Tables showing average concentrations and computed annual amounts of constituents, including nutrients, produced per square mile by the several sources such as rainfall, community sewage, urban stormwater runoff and combined sewer overflows, based on studies at Cincinnati and information from the literature, are presented. These indicate that all are significantly concentrated in some respect as to warrant

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16. Abstracts Anticipated population growth and related drainage problems and demands for water for all purposes is discussed. Tables showing average concentrations and computed annual amounts of constituents, including nutrients, produced per square mile by the several sources such as rainfall, community sewage, urban stormwater runoff and combined sewer overflows, are presented. Comments on studies and practices representing the variety of efforts to control pollution from storm water runoff or combined sewer overflows also are presented.

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SEWER SYSTEMS

The two general patterns of drainage systems for urban sewage and storm-water runoff in the United States are called "separate" systems and "combined" systems. The first includes a separate sanitary sewer system of closed conduits generally designed to take advantage of the natural slopes of the local topography to enable gravity flow to a treatment plant near a receiving stream, lake, or estuary. This is usually cne system, but there may be more where a community straddles drainage divides. The storm-water runoff is collected and transported in separate pipes, gutters, or ditch-type storm drains, to handy local waterways. There usually is more than one system of storm sewers in a community.

The combined system attempts to do the whole job by connecting the wastes as well as the roof leaders, area and footing drains, catch basins, everything, to the single large street sewers. These are designed to accomodate storm-water runoff from storms up to a selected size, since the storm-water runoff is so large compared with the dry weather flow - which is sewage. The combined sewer sub-systems (usually several) are connected to the sewage treatment plant by a system of interceptor sewers, designed to carry from 1-1/2 to 5 times the sewage flow. In dry weather the large combined sewer carries sewage to a diversion point before reaching the local outlet. At the diversion point the sewage drops through a hole in the pipe to the interceptor, or does it by more fancy means such as weirs or gates, and goes to the treatment plant. During wet weather the 1-1/2 to 5 times dry weather equivalent volume of the sewage and storm-water mixture is diverted to the treatment plant. The bulk of the mixture, not so intercepted,

consideration in appraising sources of pollution, particularly nutrients. In terms of relative production of nutrients per unit of area, community sewage heads the group, followed in order of decreasing unit production by combined sewer overflow, storm water runoff from a residential-commercial area and rainfall.

Urban stormwater runoff is considered by some to be a "resource out of place." The old rain barrel, and the cistern and pressure water system, are simple examples of this. Intercepted by roofs, parking lots, streets and other impervious surfaces, this water resource is conveniently distributed for possible storage and such practical uses as cooling, lawn and garden watering, recharge to ground, ornamental ponds, toilet flushing, delayed release to lower urban flood peaks, to name several. Selectivity or modification to reduce hazard should be examined, since storm runoff from every source may not be suitable, nor hygienically safe, for all uses.

Comments on studies and practices representing the variety of efforts to control pollution from storm water runoff or combined sewer overflows are presented. These include studies on settling, and on diversion of urban storm runoff to relieve lake enrichment, ground recharge installations for road and housing development storm drainage. Those referring to combined sewer overflows include partial and complete separation of sewers, deep tunnel storage, storage in sewers, and above-ground and below-ground storage-sedimentation tanks. Treatment of extraneous flows in sanitary sewers is also included.

Government research contract and demonstration grant programs to provide assistance to qualified workers interested in contributing to methods for control of storm and combined sewer sources of pollution are outlined.

The paper includes two figures, nine tables and 34 references.

URBAN DRAINAGE AS A FACTOR IN EUTROPHICATION*

by

S. R. Weibel**

INTRODUCTION

In the broad sense the topic, "urban drainage," includes sewage as well as storm-water runoff and combined sewer overflows. Since current research activities on the control of nutrients in connection with sewage treatment seem well documented, this paper is devoted to storm-water runoff and combined sewer overflows as sources of water pollution, including nutrient contributions, an area where much work is needed.

The urbanization explosion means that more people, more demands for water for all purposes, more wastes, more storm-water runoff are all impressed upon existing time, space, facilities, and habits, already representing huge investments. It seems appropriate to first see where this dense urbanization is expected to develop and then to consider some of the drainage problems and efforts toward control.

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**- Sanitary Engineer Director, USPHS, assigned to Federal Water Pollution Control Administration, Cincinnati Water Research Laboratory, Department of the Interior, Cincinnati, Ohio.

URBANIZATION

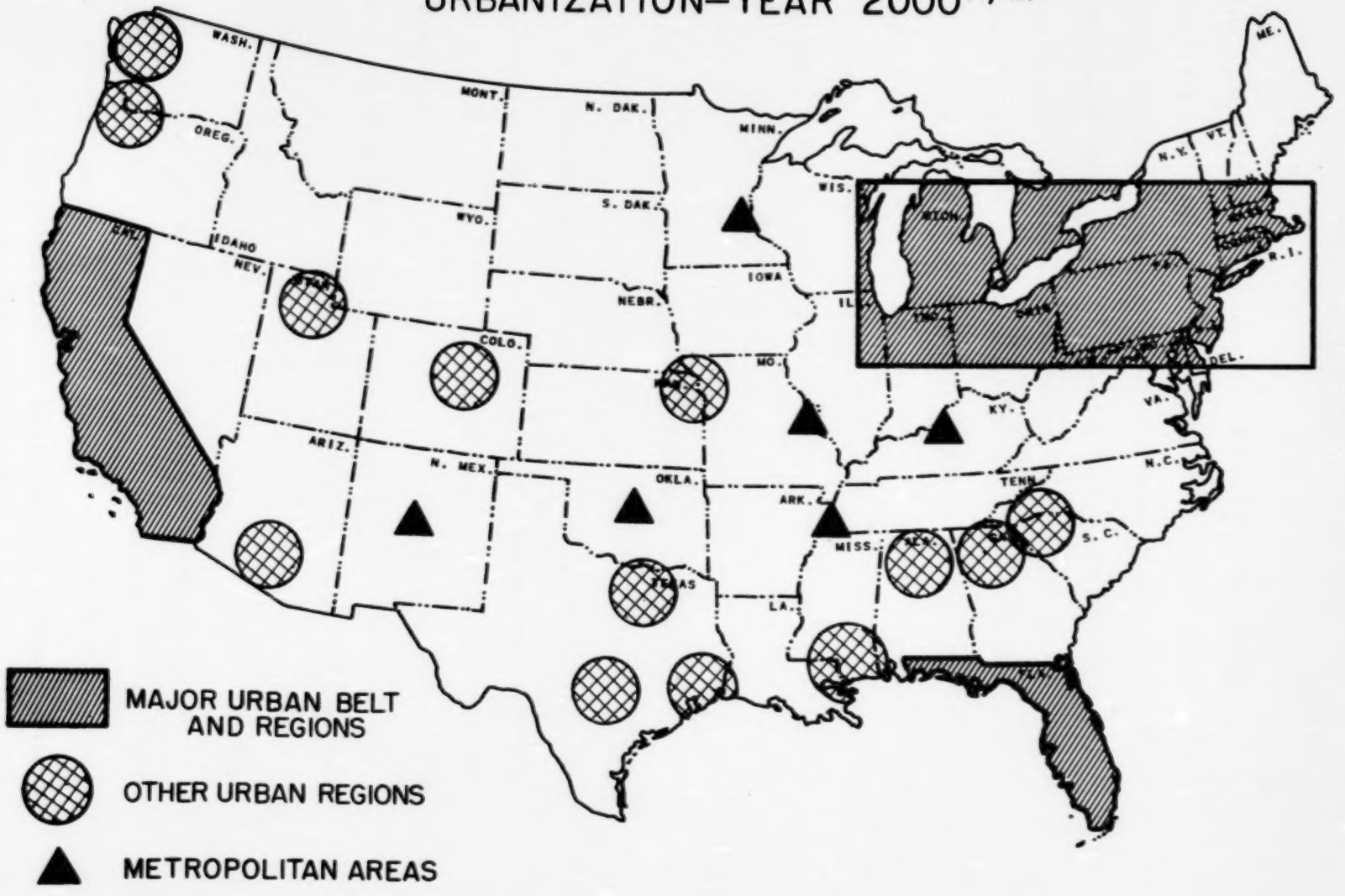
Projections in the study, "Dimensions of Metropolitanism,"[1] indicate that by the beginning of the 21st Century, some 77 percent of the 312 million population of our 48 mainland states and the District of Columbia will occupy about 11 percent of the land area. These 240 million urban dwellers are expected to locate in three major urban regions, six metropolitan areas and in 13 outlying urban regions as indicated in Figure 1.[2] They are identified as the Metropolitan Belt, stretching from the Atlantic seaboard to the Wisconsin-Illinois complex, the California and the Florida regions; six Metropolitan Areas: St. Louis, Louisville, Memphis, Oklahoma City, Twin Cities and Albuquerque, each expected to have at least one million persons; and the thirteen Urban Regions: Carolina Piedmont, North Central Georgia, North Central Alabama, Central Gulf Coast, Texas-Louisiana Gulf Coast, North Central Texas, South Central Texas, Missouri-Kaw Valley, Salt Lake Valley, Colorado-Piedmont, Puget Sound, Willamette Valley and Metropolitan Arizona.

Other sources[3] estimate that as high as 95 percent of the total population may live in urban environments at the turn of the century.

We had rather a good start on this by 1960. The population living in urban areas then was about 125 million or 70 percent of the total for the 48 mainland states plus the District of Columbia. About 98 percent of the urban population was served by community sewer systems at that time.

Figure I.

URBANIZATION—YEAR 2000[1, 2]



Although the total numbers of communities of all kinds, including housing developments of 100 or more persons have not been tabulated, the number of sewered communities has been counted at 11,350 for the 50 states and the District of Columbia in 1962.[4] About 70 percent of our sewered communities have populations of less than 5,000 persons. In 1960, sewered communities ranged in size from less than 1/2 square mile (1.30 km^2) to 454 square miles (1,176 km^2) for Los Angeles.[5] The most densely populated large city was New York, with 39 persons/acre (96 persons/hectare). The Metropolitan Belt is expected to cover 159,000 square miles (412,000 km^2) and have a population of 129 million persons.

WATER USE

Aside from future needs for increased supplies of suitable quality water for domestic, industrial and agricultural uses, demands for recreational waters will probably outrun population growth. The demographic projections into generously endowed surface water areas are consistent with this. In addition, recreation is already a large industry, which will continue to grow. An important item in the control task ahead will be the coordination of political and technical elements in the broad planning so necessary for economy and effectiveness.

RAINFALL

Rain contributes constituents directly and indirectly to surface waters. It also serves as an eroding, dissolving, and transporting agent in storm-water runoff and in combined sewer overflows. Rainfall averages 30 inches annually over the United States, ranging from less than 2 inches in the Southwest to some 150 inches in the Northwest.

The sources of rainwater constituents are the earth's soil and the by-products of man's activities. These become atmospheric pollution and wash out with rainfall. Lightning is claimed to be a minor factor in the fixation of rainfall nitrogen.[7,8] Rainwater may further eutrophication through the direct contribution of constituents such as phosphorus to surface waters.

During the storm-water runoff studies at Cincinnati many summer storms were highly local, with a downpour at some location and sometimes none at another point 1/2 mile away. Thus many times only portions of a city sewer system receive runoff. Constituent concentrations in rainfall at the urban storm-water runoff study site at Cincinnati are shown in Table 1. Concentrations of solids, chemical oxygen demand (COD) and nutrients are low as compared with those of storm-water runoff, or combined sewer overflows, or sewage, as shown in Tables 3, 5, and 7. Nonetheless, they warrant consideration. For instance, inorganic nitrogen (as N) averages 0.69 milligrams per liter (mg/l) and total acid-hydrolyzable phosphate (which can eventually become soluble phosphate), called total phosphate P, and expressed as P in this paper, averages 0.08 mg/l. These are in excess of Sawyer's[6] nutrient thresholds of 0.3 and 0.01 mg/l for inorganic nitrogen N and inorganic phosphorus P, respectively, in lake waters experiencing algae blooms.

Table 1. Rainfall Constituents

Constituent	Average* Concentration (mg/l)	Amount** (1,000 lb/sq mi/yr)****
Suspended Solids	13	57
COD	16	70
Total N(Σ 4 forms as N)	1.27	5.5
Inorg. N(Σ 3 forms as N)	0.69	3.0
Total PO_4*** (as P)	0.08	0.35

*At Cincinnati, August 1963-December 1964.

**Assuming 30 inches annually (U.S. average).

***Total acid-hydrolyzable phosphate.

****Multiply by 0.175 for 1,000 kg/km^2/yr.

The inputs of total phosphate P into Lake Erie[9] have been recently estimated as shown in Table 2.

Table 2. Total Inputs of PO_4-P to Lake Erie by Sources

Source	PO_4-P (lb/day)*
Lake Huron	< 20,000
Rural runoff	20,000
Municipal	
Detergents	70,000
Human excreta	30,000
Urban land	6,000
Industrial (direct)	6,000
Total	152,000

*Multiply by 0.454 for kg/day

Annual rainfall averages 32 inches at several large cities around Lake Erie and Detroit. Assuming that this were the annual rainfall on Lake Erie, and further, that its total phosphate P were the 0.08 mg/l observed at Cincinnati, the rainfall phosphate contribution to the 9,910-square mile (25,700 km^2) lake might be 10,000 lb/day (4,500 kg/day) or about 6-1/2 percent of the total load. On the other hand, if the rainfall total phosphate P were the 0.027 mg/l found in rain at the

Coshocton, Ohio[10] which approximates the 0.025 mg/l suggested total phosphate P goal for western Lake Erie[9] the direct rainfall contribution would be 2 percent of the total load.

MUNICIPAL SEWAGE

Municipal sewage is a major source of waterborne pollution, including plant nutrients. Unfortunately, routine analyses and characterizations of sewage have rarely included information on nutrients, particularly on phosphates; therefore data are scarce and fragmentary. In general, sewage derives from excreta, ground garbage, laundry, and other cleaning wastes from households, wastes from commercial and industrial process, and cleanup and wash operations from innumerable industrial activities. Sewage may carry infectious and toxic agents, plant nutrients, persistent organics, oxygen-demanding substances, petrochemical , oil, radioactive substances, heat, acids and sludges, to name several.

In the separate sewer system sewage is independently collected and transported in a pipe system to treatment before discharge. The storm-sewer system, or subsystem, independently carries storm-water runoff to convenient watercourses. The two functions are combined, rather poorly, in the combined type system, wherein the sewage, which is the only flow in the large sewers during dry weather, is diverted from that sewer to an intercepting sewer before reaching the outlet, and is led to the sewage treatment plant. During wet weather the diversion-to-interceptor arrangement accepts an amount of the sewage-storm water mixture equal to 1-1/2 to 5 times sewage flow during dry weather, depending on design and other circumstances. The rest of the mixture, which may have flows of from 50 to 200 times sewage flow during dry weather overflows directly to a watercourse. Past

studies, mostly studies of flow relationships and dilutions rather than amounts of constituents, have estimated the annual loss of sewage through overflows at about 3 percent, although during storms the losses might be as high as 60 or 90 percent, depending on the storm intensity and diversion capacity.[11] Thus, the character and amount of raw sewage escaping untreated through combined sewer overflows are of interest. So, also, are the character and amount of storm water involved, and of the sewage filth stranded during dry weather, because of the low velocities, awaiting the scouring effect of storm-water flow. Stormwater constituents and stranded filth were not included in the 3 percent annual loss estimates. In fact, as will be shown later urban storm-water runoff itself, without any sewage, may contain annually quantities of some of these same contaminants amounting to more than 3 percent of those of raw sewage.

A modest review of literature, for a general characterization of community raw sewage, including plant nutrients, was rather disappointing because of the incomplete, out-of-date, and ambiguous nature of much of the information. Rather than repeat this, the author presents in Table 3 what he believes, from a review and discussions with other workers, to be a fair and up-to-date characterization of community sewage (mostly domestic).

Table 3. Generalized Community Raw Sewage Composition
(Largely Domestic)

Constituent	Average Concentration* (mg/l)	Amount Produced* at Indicated Population Density (1,000 lb/sq mile/year)*** 10 Pers/acre (25 Pers/ha)	50 Pers/acre (124 Pers/ha)
Susp. Solids	200	390	1,900
COD	350	680	3,400
BOD	200	390	1,900
Total N (Σ 4 forms as N)	40	78	390
Inorg. N (Σ 3 forms as N)	30	58	290
Total PO_4** (as P)	10	20	97

*Assuming 100 gpcd.

**Total acid-hydrolyzable phosphate (which can eventually become soluble phosphate).

***Multiply by 0.175 for 1,000 kg/km^2/yr.

The amounts of constituents produced annually per unit area for the various sources will be compared later in this paper. In passing, note that at 10 persons/acre (25/ha), which is the Cincinnati city population density, 3 percent annual loss of raw sewage nutrients (Table 3) would amount to 1,700 and 600 pounds/square mile (300 and 105 kg/km^2) of inorganic nitrogen N and total phosphate P, respectively. Thirty inches annual rainfall, at Cincinnati observed concentrations (Table 1) would contain 3,000 and 350 pounds/square mile (530 and 61 kg/km^2) respectively of those nutrients.

Research is continuing, on methods for removal of nutrients, as well as other constituents, from sewage, and from effluents from some types and stages of conventional sewage treatment processes. These are documented in the literature under authorship of authorities such as Sawyer, Rohlich, and others.[12] A recent review, pertinent to the topic of this Symposium, entitled "Eutrophication and Water Pollution," by Martin and Weinberger, includes a review of treatment.[13] It is concluded that methods for substantial removal of nutrients from sewage are available, for a price.

It should be emphasized that the sewage treatment plant, however sophisticated, can treat only the sewage it receives. Uncontrolled escape of significant portions of the raw sewage from combined sewer overflows, or from overloaded or infiltrated separate sanitary sewers, may seriously discount plant performance.

goes out the storm sewer outlet to the local watercourses. The bulk of the mixture may discharge to the local water course at a rate from 50 to 200 times that of the sewage rate of flow, depending on population density, storm size, and other factors.

There are some 11,350 communities in the 50 States and the District of Columbia with sewer systems of either of the two types, or combinations of both and of course, variations of all. Some of these systems are badly overloaded, or otherwise abused, because of failure to keep up with the pace of today's urbanization with its rapid population and industrial growth, and the conversion of vegetated surfaces to paved surfaces. Other common causes are leaky and broken pipes and joints in street sewers, blanked stubs and house sewers; misuse of sanitary sewers because of deliberate or unintentional connection of roof and and other storm drains; and many others. Some of the items warrant strict control over the quality of installation and maintenance, more control than many communities have been willing to pay for.

STORM-WATER RUNOFF, SEPARATE SYSTEMS

Of the 11,350 sewered communities in the 50 states and the District of Columbia, 9,013 have "separate" type sewer systems, 1,305 have "combined" systems, 618 have both types and the remaining 414 are unidentified as yet. So, some 9,631 communities, 88 percent of the identifiable total are wholly or partly sewered by separate systems.[4]

With growing awareness of the pollutional significance of raw sewage included in combined sewer overflows, the complete separation of storm water from sanitary sewage, and adequate treatment of the latter have gained support. Storm-water runoff itself has been viewed with suspicion. This is not surprising, when one wonders what happens to residues from vehicle wear and drippage, garbage from careless handling by workers and householders, animal droppings, construction-job silt, runoff from generously treated gardens and lawns, dustfall, and so on. For instance atmospheric dustfall can average approximately 300,000 pounds/square mile/year in a city, with some parts of the city reaching 80,000 pounds/square mile/month (52,500 kg/km^2/yr and 14,000 kg/km^2/month). Sampling of street runoff by Palmer at Detroit,[14,15] Sylvester at Seattle,[16] and by Wilkenson[17] and others in England and elsewhere[18] show that urban storm-water runoff is far from clean.

In 1961, Woodward of the U.S. Public Health Service inspired support in that agency for study of urban storm-water runoff. A 27-acre (11 ha) separately sewered residential-light commercial section of Cincinnati was chosen for study. The storm sewer there was instrumented to gauge runoff and automatically collect samples. This was a relatively clean type of urban land use, including single and multiple family dwellings, stores, local streets, part of a public park, parking lots, and residential lawns, and gardens. The percentage of impervious area, such as roofs, streets, and parking lots was 37 and the coefficient of runoff, based on the ratio of summed amounts of runoff and rainfall, was also 37 percent. The nature of this runoff is shown in Table 4 by average concentrations and unit annual yields

TABLE 4

Urban Storm-Water Runoff

(from 27-acre (11 ha) residential-light commercial separate sewer area)

Constituent	Avg.Conc. (mg/l)	Amount* (1,000 lbs/sq mi/yr**)
Susp. solids	227	366
COD	111	178
BOD	17	27
Total N (4 forms as N)	3.1	5
Inorg. N (3 forms as N)	1.0	1.6
Total phosphate (as P)	0.36	0.6

*Assuming 30 inches annual rainfall and 37 percent runoff.

**Multiply by 0.175 for 1,000 $kg/m^2/yr$.

for several parameters, including plant nutrients. This runoff carried suspended solids concentrations exceeding that of raw community sewage and BOD equal to the concentration in effluent from secondary sewage treatment plants. The nutrient contents, with inorganic nitrogen N averaging 1.0 mg/l and total phosphate P, 0.36 mg/l are considerably in excess of Sawyer's[6] thresholds for trouble. There was evidence[19] that storm-water runoff suspended solids concentrations varied with rate of runoff, peaking at runoff peaks. Runoff rates were not necessarily high early in the storm. There was sometimes more than one peak, each accompanied by an increase in suspended solids.

Because all of this is so closely related to recreational waters, the microbiological quality for this same runoff is presented in Table 5. In many places in this country the limit on total coliform content of waters used for full recreation, that is, full body contact such as swimming is 1,000/100 ml. Since 90 percent of the runoff samples contained more than 2,900 total coliforms/100 ml, this water would be condemned for full recreational use. Salmonella have been found in this runoff.

It is unlikely that the residential-light commercial area urban runoff characterized in Tables 5 and 6 is representative of runoff from high density residential sections, industrial sections, market areas, railroad or trucking operation areas, parks, zoos, or downtown city sections. It is likely that these differ both in quality and quantity.

TABLE 5

Urban Storm-Water Runoff

(27-acre (11 ha) residential, light commercial, sep. sewer area)

Constituent	Numbers/100 ml exceeded in designated % of sample		
	90%	50%	10%
Total Coliforms	2,900	58,000	460,000
Fecal Coliforms	500	10,900	76,000
Fecal Streptococci	4,900	20,500	110,000

TABLE 6

Characteristics of Dry Weather (Sewage)
and
Wet Weather (Sewage and Storm Water) Flows

Constituent	Average concentrations (mg/l)				
	East Bay, Calif.[21]		Buffalo, N.Y.[20]		S. Oakland County, Mich.[22]
	South Intercept.	North Intercept.	Bird Ave.	Bailey	Twelve Town Dr. District
	Dry / Wet	Dry / Wet	Dry / Wet	Dry / Wet	Dry / Wet
Susp. Solids	336 / 162	--- / 162	158 / 554	126 / 436	198 / 176
BOD	449 / 178	285 / 195	162 / 100	127 / 121	52 / 140

COMBINED SEWER OVERFLOWS

Combined sewer overflows are individually unique and variable. In addition to variables attributable to the source of the storm water are those of the escaping sewage, and those of the sewer system. Unsatisfactory hydraulic design permits low dry weather flow velocities to strand sewage solids in the relatively large combined sewers. These accumulations are dislodged, mixed, and partly lost in the overflow during storms. The pipe system, if it has a short concentration time, may show a first flush of highly polluted overflow, followed by a tapering off. If the system is extensive, with long concentration time, the dislodged materials may arrive sequentially from various distances. The result then is a prolonged overflow of high strength mixture. Classic studies at Buffalo bring this out.[20]

The uniqueness of combined sewer overflows is evident from field data, shown in Table 6, which characterize the raw sewage (dry weather flow) and the sewage and storm-water mixutre (wet weather flow) from three urban combined sewer systems. The dry weather sewage suspended solids concentrations at East Bay, California[21] and at Twelve Town Drainage District, Michigan[22] were higher than those of their wet weather combined sewage flows, whereas those at Buffalo, N.Y.[20] were the reverse. A reversal in the BOD dry and wet weather flow concentrations is also evident for East Bay and Buffalo vs. Twelve Town Drainage District. It is obvious from these that there are wide differences, in at least these parameters, between cities.

Studies of Connor Creek combined sewer overflows at Detroit, Michigan and of the Allen Creek storm water drain at Ann Arbor, Michigan[23,24] provide nutrient information of interest. The concentrations and estimated amounts for the combined sewer overflows at Connor Creek are shown in Table 7. The report[24] indicates that nitrogen and phosphate discharges from the combined system (Connor Creek, Detroit) were 4 and 3 times greater, respectively, on the average than those of the separate storm sewer system (Allen Creek, Ann Arbor).

TABLE 7

Combined Sewer Overflow

Constituent	Average Concentration (mg/l)	Amount* (1,000 lb/sq mi/yr)**
Susp. solids	150	162
Org. N.	0.37	0.40
Ammonia N	3.25	3.5
Total PO_4 (as P)	3.0	3.2

*Assuming concentrations apply to reported 4-1/4 billion gallons discharged during one year from an area of 32.8 sq mi (85.0 km^2)[23,24] .

**Multiply by 0.175 for 1,000 $kg/km^2/yr$.

Unit amounts from the foregoing tables for the various sources are listed in Table 8. As previously indicated there is good reason to believe that concentrations and amounts may vary widely from one environment and its particular sewer system, to another. In view of this, Table 8 is offered merely as a rough indication of what some of these values

Table 8. Amounts of Pollution from Urban Drainage

Constituent	Amount (1,000 lb/sq mile/yr)***										
				Community Sewage (mostly domestic)							
				10 persons/ac(25/ha)				50 persons/ac (124/ha)			
	Rainfall*	Sep.Syst. Runoff**	Comb.Syst. Overflow	Raw	3%	5%	10%	Raw	3%	5%	10%
Susp. Solids	57	366	162	390	12	20	39	1,900	57	95	190
BOD	--	27	--	390	12	20	39	1,900	57	95	190
ΣN	5.5	5.0	0.40	78	2.3	3.9	7.8	390	12	20	39
Inorg. N.	3.0	1.6	3.5	58	1.7	2.9	5.8	290	8.7	14	29
Total PO_4 (as P)	0.4	0.6	3.2	20	0.6	1.0	2.0	97	2.9	4.8	9.7

* 30 inches/year.

** 30 inches/year and 0.37 runoff coefficient.

*** Multiply by 0.175 for 1,000 $kg/km^2/yr$.

might be, and further, that it may stimulate others to generate factual data for study of the significance of sources of pollution of this nature. In addition to the amounts of constituents in raw community sewage at the two population densities of 10 and 50 persons/acre (25/ha, 124/ha), amounts represented by 3, 5, and 10 percent of the raw sewage are included to give an idea of what a 3% annual loss of raw sewage to combined sewer overflows would be, and the amounts in effluents from 90 and 95 percent removal by treatment from community sewage. Referring to the phosphate parameter, of particular interest in connection with eutrophication, urban sources such as combined sewer overflows and possibly separate storm water runoff become increasingly significant.

DISTRIBUTION OF COMMUNITIES WITH COMBINED SEWER SYSTEMS IN U.S.

The number of communities in the United States served by the two types of sewer systems was presented in the previous section on Storm Water Runoff, Separate Systems. Some 1,923 communities, 18 percent of the communities with identifiable systems, are partly or wholly sewered by "combined" types systems.[4] Many of our older and larger cities are served by combined sewers. The distribution geographically by states is also of interest in that it reveals that 98 percent of the communities having combined sewer systems are located in a band of states across the northern part of the country and the west coast. The distribution is tabulated in Table 9, showing for Pennsylvania for example, the first entry, that that state has 271 communities with "combined" or "both" sewer system types, and that these represent 32 percent of all communities with identifiable types of sewer system in that state.

Table 9. Distribution of Communities Served by "Combined" Sewer Systems

States with more than 10*									States with less than 10*					
State	No.*	%**	State	No.*	%**	State	No.*	%**	State.	No.*	%**	State	No.*	%**
Pa.	271	32	N.H.	55	79	Conn.	24	34	Del.	7	35	Colo.	1	1
Ind.	205	71	Mass.	51	30	Neb.	18	6	Tenn.	6	5	Miss.	1	1
Ill.	183	34	N.D.	48	27	N.J.	18	7	Va.	5	3	N.C.	1	< 1
Ohio	179	41	Ore.	43	29	Alaska	13	62	Ga.	5	2	Ala	0	0
Mich.	162	57	Vt.	41	89	Calif.	12	2	Nev.	4	11	La.	0	0
N.Y.	102	23	Ky.	32	20	Idaho	12	13	Kans.	4	1	N.M.	0	0
Wis.	85	20	Minn.	30	7	Md.	11	10	R.I	3	12	Okla.	0	0
Me.	70	69	Ia.	28	7	Mont.	11	10	Ark.	2	2	S.C.	0	0
W.Va.	66	46	S.D.	27	15				Fla.	2	1	Utah	0	0
Wash.	55	31	Mo.	26	7				Tex.	2	< 1	Wyo.	0	0
									Ariz.	1	2	Hawaii	0	0

*Number of communities served by "combined" or "both" (combined and separate) sewer systems.

**As percent of communities served by all types of identified system ("separate", "combined", "both" (separate and combined) within State.

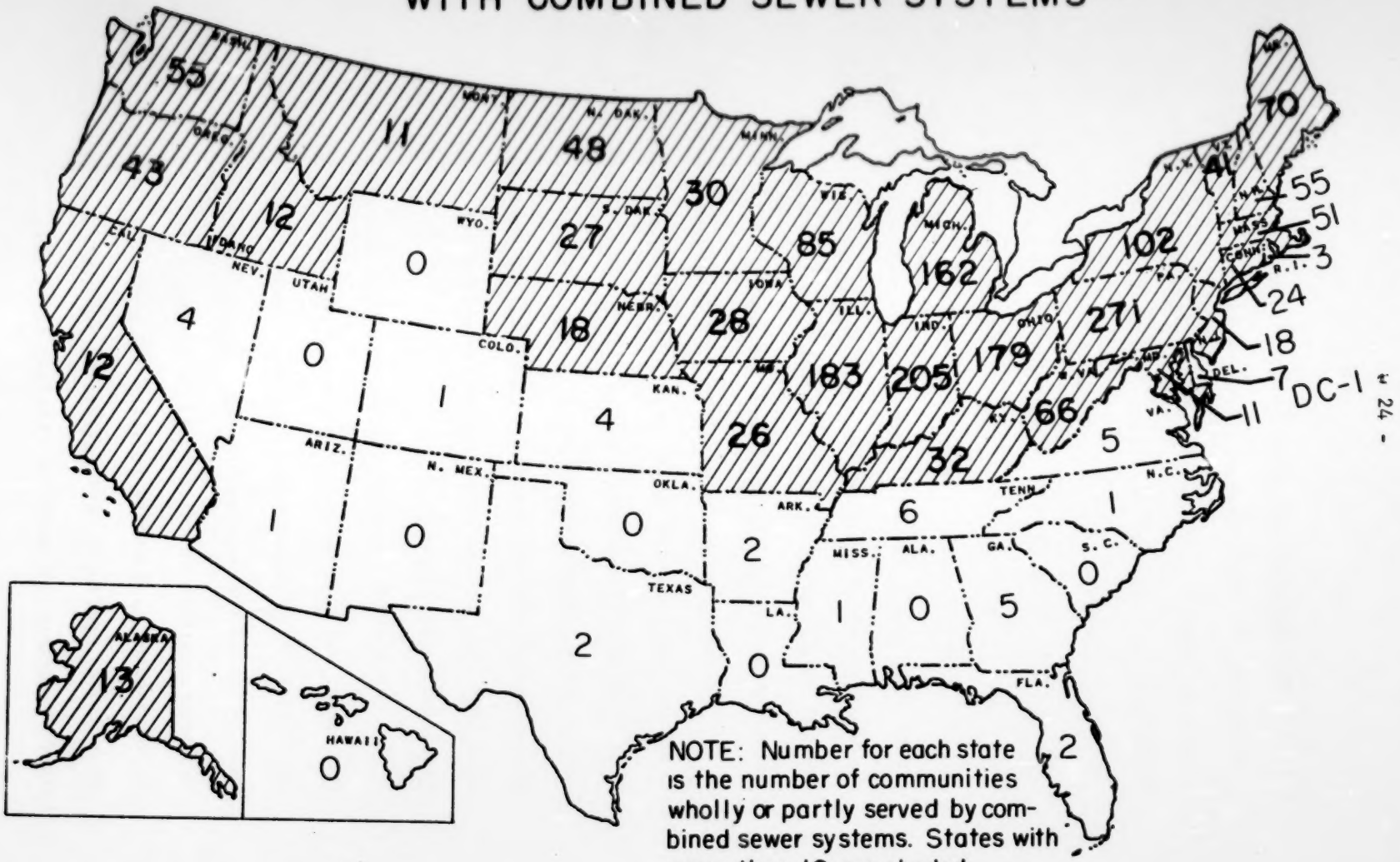
The geographical distribution of numbers of communities with "combined" or "both" types of sewer systems tabulated in Table 9 is shown on Figure 2. Comparing the distribution of communities with combined sewer systems on Figure 2 with that of the urbanization forecast on Figure 1, the expected Metropolitan Belt, stretching from the Atlantic Ocean through the Chicago complex, will blanket possibly one-third to one-half of all the communities with combined sewer systems in the country. Several cities in other parts of the country expected to be involved in areas of high density urban occupancy, and which now have combined sewer systems, are Seattle, Tacoma, Portland (Oregon), Pueblo, Kansas City, St. Louis, Minneapolis-St. Paul, San Francisco, Eureka (California), Atlanta, and Louisville.[1]

In addition to the waste control challenges posed by existing combined sewer systems in the path of urban intensification, many of these areas are generously endowed with surface waters for which future water recreation demands will be enormous. Add to this the occurrence of eutrophication in some of these areas now, and one gets some idea of the immensity of the preventive problems ahead; also of the current ones.

The problems facing a particular city or area are unique to that area, and the preventative program may have to be tailored to its needs. Past shortcomings include: lack of understanding or application of adequate urban hydrology, underestimated rate of growth in design, failure to utilize modern business tools to win adequate appropriations, reluctance to write off old investments in long obsolete works and to modernize, and failure to buy the goods and services to properly operate and maintain existing facilities.

Figure 2

DISTRIBUTION OF COMMUNITIES WITH COMBINED SEWER SYSTEMS[4]



PREVENTIVE MEASURES FOR CONTROL

Urban storm-water runoff is considered by some to be a resource out of place. Possibly a clear example of the usefulness of storm water as a resource is the old rain barrel, or the current version, the cistern and pressure water system in fringe area homes. Intercepted on roofs, parking lots, streets and similar impervious surfaces, stormwater is conveniently distributed for possible local storage for use for cooling, lawn and garden watering, recharging to ground, ornamental ponds, toilet flushing, or for delayed release from storage for reduction of flow peaks in storm or combined sewers. Roofs, for example, comprised 30 percent of the total impervious surface in the residential-commercial runoff study area of Cincinnati. However, runoff from every type of surface or land use is not suitable, or hygienically safe for all uses. Selectivity, or modification to reduce hazards, for example, disinfection when body contacts are involved in the use.

Sedimentation of Storm Water Runoff at Cincinnati

Laboratory bench experiments on quiescent settling, and settling and chlorine disinfection, of storm-water runoff from the Cincinnati study area indicated that less than 1 hour of settling did not substantially reduce COD, BOD, nitrogen, phosphates, or solids. Total phosphate removals were 15 percent in 1 hour and 30 percent after 4 hours of quiescent batch settling.[25]

Diversion of Storm Water Drainage at Seattle

Sources of nutrients and other pollutants, including street gutter storm runoff, reaching Green Lake in Seattle, Washington, were studied because aquatic vegetation interfered with recreational use. Recommendations were to discontinue most urban storm-water drainage

to the Lake and to add 10,000 gallons per day (38,000 1/day) of city water supply to the Lake to reduce the overenrichment.[16]

Ground Recharge of Storm-Water Runoff, Long Island, New York

On Long Island, New York, the sandy subsoil makes possible an economical means of storm water runoff disposal, the ground recharge basins. These are used for disposal by the state for road drainage, by housing contractors for dwelling project storm runoff, by industry for storm-water runoff and, in addition, for treated wastewater. Many of the small basins are underground pits, others are fenced open pits along rural roads, and larger installations are excavated open pits sized to contain runoff from a large storm. One of the latter, receiving road drainage, includes two dugouts, one serving as a desilting basin and the other as a seepage basin.[26]

Partial Separations, Toronto, Canada

Toronto has started a road sewer program involving construction of new storm sewers to receive street storm-water runoff only. This is expected to divert 30 to 60 percent of the flow from heavily loaded combined sewers where needed and so relieve local flooding and increase sewage interception efficiency. The unit capital cost for this is about $7,500/acre ($18,500/ha), instead of the $17,000/acre ($42,000/ha) cost for a new separate sanitary sewer system, or $21,500/acre ($53,000/ha) for a new separate storm sewer system.[27]

Complete Separation Ultimately, Metropolitan, Washington, D.C.

The cost for complete eventual separation in Metropolitan Washington, D.C. is estimated at $20,000/acre ($50,000/ha). Interim control measures include separation of residence and building sewers, and increasing interceptor capacities to reduce overflows in sensitive areas, including transferral of overflows to a less sensitive outlet environment.[28]

Storage in Combined Outlet Sewers, Twelve Town Dr. Dist., South Oakland County, Michigan

A high weir skimming structure at the outlet of combined sewers serving a 24,500-acre (9,900/ha) drainage area creates 100 acre-feet (123,000 m^3) storage in outlet sewers before overflow. This has reduced the number of spills. Oil, grease and floatables are retained. Spills do not appear aesthetically offensive. The contents retained in the sewer are metered into the Detroit System for treatment. The 54-inch (137-cm) magnetic flow meter also automatically limits maximum flow to the purchased capacity. The installation includes automatic flow gauging and sampling equipment for dry and wet weather flows, rainfall gauges, and a laboratory. Analyses include suspended solids, volatile suspended solids, oil and grease, BOD, DO, pH, chromium, cyanide, copper, and microbiological determinations.[22]

Storage in Combined Underflow Tunnels, Chicago, Illinois

Chicago plans a deep large tunnel 33 to 50 feet (10.1 to 15.2 m) in diameter, 200 to 400 feet (61.0 to 121.9 m) deep in limestone rock, together with branch tunnels and shafts, to store excess combined flow, to be pumped to the sewage treatment plants later. This is expected to absorb the flow from a 2 to 2-1/2 inch (5.1 to 6.4 cm) rainfall without discharging any untreated water from the mainstream underflow,

a one-year frequency, and the tunnel and surface system could handle a 100 year storm without overflow to Lake Michigan. The cost was estimated at some $4,200/acre ($10,400/ha), equivalent to 10 percent of an estimated $42,000/acre ($104,000/ha) for separation and a new sanitary sewer system for Chicago. The first "underflow sewer" under Lawrence Ave., as part of the system, is about to be constructed. The "mole" or tunnel boring machine method is expected to save $2 million and two years construction time over the open-cut method.[29]

Holding Basins for Extraneous Sanitary Sewer Flows, Johnson County, Kansas and Kansas City, Mo.

Construction of holding basins to accommodate extraneous flows during wet weather in sanitary sewer systems to eliminate troubles from sewer backup and/or overflow has been reported for parts of Johnson County, Kansas and Kansas City, Missouri. The extraneous flows resulted from areaway and foundation drain connections to the sanitary sewer.[30]

Treatment of Combined Sewer Overflow, Grosse Pointe Woods, and Harper Woods, Michigan

Sanitary and combined sewers serving Harper Woods and Grosse Pointe Woods discharge to Grosse Pointe interceptor and to the Detroit municipal system. Wet weather combined flows in excess of 8,000 gpm (30,000 1/min) are diverted to a sedimentation-skimming tank, the effluent of which discharges to Milk River and Lake St. Clair during storms causing overflow. The contents of the tank are flushed to the interceptor, when capacity becomes available, for treatment by Detroit.[31]

Monitoring Combined Sewer Overflows, Cincinnati, Ohio

The City of Cincinnati has almost completed installation of a combined sewer overflow monitoring system, parts of which are now in operation. Signaling switches on each of 250 combined sewer overflow-interceptor locations grouped on 87 party lines signal any overflow because of storm or clogging of the interceptor device. An operator calls the political subdivision responsible for maintenance at the interceptor location. A central map lights the location of the overflow. The operator delays his call 10 minutes. If during that time numerous other signals within the area show overflows, rain is inferred and another course of action is taken. Daily printout records enable study of overflow patterns and maintenance operations. It is expected that the operation will reduce pollution problems throughout the metropolitan area.[32]

Storm Water Tanks for Combined Sewage, Berlin, West Germany

The City of Berlin, two-thirds of which has separate sewers and the remaining one-third has combined, has installed covered settling tanks at a number of pump station locations. These receive flows in excess of the 5 and 6 times dry weather flow at which the intercepting devices are set. They provide complete temporary storage of small peak overflows and settling of large peaks before overflow to local streams. After a storm the tank contents are flushed into the city sewer system. Before the tanks were built about 55 percent of the total waste reaching the sewers received treatment. After the tanks were put into operation 85 percent received treatment either by the central plant or the storm-water settling tanks. Scarcity of space to locate tanks was overcome in one case by locating the tank below a school yard with offset manholes outside the yard at a pump station, and in another case

by locating two tanks beneath a street, with appropriate reinforcement for the load. Usually tanks were installed at pump station grounds.[33]

The above cases are selected to indicate the variety of recent practices to control pollution from sewers carrying storm water or storm water and sewage. Information on plant nutrient control in storm water and combined sewer overflows is incomplete and scarce.

The discharge of polluting wastes from storm drainage systems and overflows from combined sewers is a distinct challenge to the ingenuity of municipal officials, consulting engineers, universities and corporations engaged in research and development, as well as to equipment manufacturers. Polluting discharges from combined storm and sanitary sewers occur during wet-weather periods when the carrying capacity of the sewers is exceeded due to the large amounts of storm water entering the sewers. The normal, or dry-weather flow is prevented from overflowing continuously by means of overflow weirs, mechanical regulators, valves, and other devices. They permit overflows to occur when sewer flows reach a predetermined level.

Separation of the storm water from the sanitary sewage can be at least a partial answer to the problem since, if the systems are completely separated, the most concentrated waste load can be conveyed to and treated at the waste treatment plant. We have come to recognize in recent years, however, that surface runoff also contains significant amounts of pollutants - some cases nearly as much as sewage - so that separation of sanitary wastes is now believed to be only a partial solution to the total problem.

Congress had these factors in mind when the current storm and combined sewer pollution control demonstration grants were authorized. Section 6 (a) (1) of the Federal Water Pollution Act authorizes "--- grants to any State, municipality, or intermunicipal or interstate agency for the purpose of assisting in the development of any project which will demonstrate a new or improved method of controlling the discharge into any waters of untreated or inadequately treated sewage or other wastes from sewers which carry storm water or both storm water and sewage or other wastes---." The Federal Government can provide up to 75 percent of the estimated reasonable cost of individual research, development, and demonstration projects. The applicant must provide assurances that local funds are or will be available to pay the remainder of the cost. Application for contract support for pertinent research and development projects will also be considered.[34]

The Administration has prepared an outline of technical areas in which those who wish to participate in the task of controlling or abating pollution from storm and combined sewers are encouraged to consider. The outline and detailed information concerning the Program and application forms may be obtained by writing to:

Office of Research and Development
Federal Water Pollution Control Administration
U. S. Department of the Interior
633 Indiana Avenue, N. W.
Washington, D. C. 20242

SUMMARY AND CONCLUSIONS

By the year 2000 about 240 million persons, 77 percent of the expected 312 million population in the 48 mainland states and the District of Columbia will occupy 22 highly urbanized areas, about 11 percent of the land. Among these are three large regions identified as the Metropolitan Belt, stretching across the northern states from the Atlantic Ocean to the Chicago complex, the California region, and the Florida region.

Intense urbanization regions include those now heavily endowed with potential recreational waters. The demands for water recreation will probably outrun population growth.

Rainfall, sampled at Cincinnati, contains nitrogen and phosphate-P exceeding Sawyer's thresholds for algae problems.

Municipal sewage is a major source of plant nutrient pollution. Losses of raw sewage through combined sewer overflows, usually estimated at 3 percent, do not include scourings of accumulations of putrescible material from combined sewers during storms, nor do they account for pollutants in the storm water itself. Although some investigators recognized this earlier, and awareness is catching on, factual data on the character of combined sewer overflows, and corrective methods and performances, are very scarce, and more so concerning plant nutrients.

The sewage treatment plant, however sophisticated, can only treat what it receives. The escape of sewage through overflows, or bypassing because of sewer system insufficiencies, can seriously discount the performance of an excellent plant.

Some sewer systems "separate" or "combined" alike are overloaded or otherwise abused because of failures to keep up with growth of population, industry, and impervious surfaces.

Eighty-five percent of some 11,000 communities with identifiable types of sewer system are wholly or partly served by "separate" systems. Although the concept of complete separation and adequate treatment of sewage has gained support, the quality of storm water runoff itself has become increasingly suspect as a result of exploratory street runoff samplings years ago and more recent urban area runoff studies. Storm-water runoff from a separately sewered residential-light commercial urban area in Cincinnati contained inorganic nitrogen averaging 1.0 mg/l and total acid-hydrolyzable phosphate-P averaging 0.36 mg/l, both considerably higher than Sawyer's thresholds for algae problems. Other pollutants in the same runoff warrant consideration, including the microbiological indicators, which would condemn this runoff for body contact recreational use. Data on runoff from other (and probably less clean) urban environments are needed.

Comparison of suspended solids and BOD concentrations in dry weather (sewage) and wet weather (sewage plus storm water) flows in combined sewer systems indicates wide variations between cities. Combined sewer overflow ammonia nitrogen averaged 3.25 mg/l and total phosphate-P, 3.0 mg/l, at one city for which plant nutrient data were available.

Seventeen percent of the 11,000 sewered communities beforementioned are wholly or partly served by "combined" sewer systems. From one-third to one-half of all communities served by combined systems are located in the projected Metropolitan Belt. A dozen large cities in other projected heavily urbanized areas also have combined sewer systems.

Since urban drainage problems are unique to each city environment, the program for control may have to be a unique combination of methods, rather than some single off-the-shelf measure. Problems of urban hydrology, growth prediction, adequate appropriations, writing off obsolete works, purchasing adequate installation, operation and maintenance, are among the challenges.

Urban storm water runoff is considered by some to be a "resource out of place." The old rain barrel, and the cistern and pressure water system in fringe area homes, are simple examples of the usefulness of this resource. Intercepted by roofs, parking lots, streets and other impervious surfaces, this water resource is conveniently distributed for possible storage for use for cooling, lawn and garden watering, recharge to ground, ornamental ponds, toilet flushing, delayed release from storage to reduce urban flood peaks, and other uses. Selectivity, or modification to reduce hazard, should be examined, since storm runoff from every source may not be suitable, nor hygienically safe, for all uses.

Briefs on studies or on installations representing a variety of efforts to control pollution from storm water runoff or from combined sewer overflows are presented. Those concerning storm-water runoff include studies on settling, on diversion to relieve lake overenrichment, and a description of ground recharge installations. Those referring to combined sewer overflows include partial and complete separation of sewers, deep tunnel storage, storage in sewers, and above ground and below ground storage-sedimentation tanks. A case of treating extraneous flows in sanitary sewers is also mentioned.

Government research contract and demonstration grant programs for assistance for qualified workers interested in contributing to methods for control of storm and combined sewer sources of pollution are outlined.

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